EUROPEAN PATENT APPLICATION

(72) Inventor: Ishihara, Kunihiko, c/o NEC Corp.
7-1, Shiba 5-chome
Minato-ku,
Tokyo (JP)
Inventor: Yamamoto, Hidefumi, c/o NEC Corp.
7-1, Shiba 5-chome
Minato-ku,
Tokyo (JP)
Inventor: Hayashi, Kazuhiko, c/o NEC Corp.
7-1, Shiba 5-chome
Minato-ku,
Tokyo (JP)
Inventor: Fujikata, Jun-Ichi, c/o NEC Corp.
7-1, Shiba 5-chome
Minato-ku,
Tokyo (JP)

(74) Representative: Glawe, Delfs, Moll & Partner
Patentanwälte
Postfach 26 01 62
D-80058 München (DE)

(54) Magnetoresistive effect element.

(57) The magnetoresistive effect element (1a) comprising an artificial lattice multilayered structure (1A) comprising a thin magnetic layer (2a, 3a) and a nonmagnetic layer (4a) at least once successively deposited and bias field applying means for applying a bias magnetic field to the artificial lattice multilayered structure (1). The layer (3a) has a coercive force H_{C3} which is greater a the coercive force H_{C2} which the layer (2a) has. The bias field applying means applies a bias magnetic field to the artificial lattice multilayered structure (1A) so that an orientation of residual magnetization of the another thin magnetic layer (3a) is the same as an orientation of a bias magnetic field to be applied to the artificial lattice multilayered structure (1A). The magnetoresistive effect element (1a) enhances regenerated outputs and also improves symmetry of regenerated waveforms.

FIG. 2A
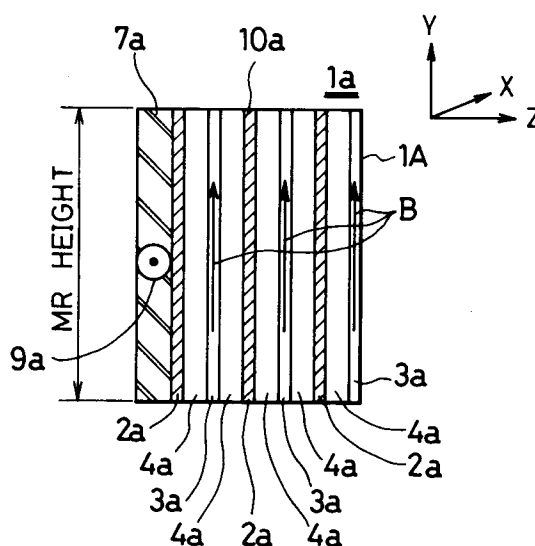
The invention relates to a magnetoresistive effect element for reading out a magnetic field intensity as a signal in magnetic substances such as magnetic medium.

Recently, there has been developed the improvement of sensitivity of a magnetic sensor and the densification in magnetic recording, and following such development, there has also developed a magnetoresistive effect type magnetic sensor (hereinafter, referred to simply as a MR sensor) and a magnetoresistive effect type magnetic head (hereinafter, referred to simply as a MR head). Both of a MR sensor and a MR head read out external magnetic field signals in accordance with a change in a resistance of a reading sensor composed of magnetic material. Both of a MR sensor and a MR head have a characteristic that a relative speed to a recording medium is not dependent on generated outputs. Hence, a MR sensor can obtain a high sensitivity, and a MR head can obtain a high output even in highly densified magnetic record.

Japanese Patent Public Disclosure No. 4-218982 laid open to public on August 10, 1992 has suggested an artificial lattice magnetoresistive effect layered structure which has a multilayered structure composed of a magnetic layer and a non-magnetic layer successively deposited and which exhibits a large change in magnetic resistance generated due to even a small external field. In this artificial lattice magnetoresistive effect layered structure, a magnetic layer has a different coercive force from that of a magnetic layer deposited adjacent thereto via a non-magnetic layer. A magnetoresistive effect element disclosed in the above mentioned Disclosure exhibits a few percents to tens of percents of resistance change rate even for an external magnetic field having an intensity ranging from a few of Oe to tens of Oe.

Though the magnetoresistive effect element can operate even with a small external magnetic field, it necessary to apply an external bias magnetic field to the magnetoresistive effect element to obtain symmetrical regenerated waveforms of signals, if the magnetoresistive effect element is to be used as a practical sensor or magnetic head.

There has been reported another magnetoresistive effect layered structure in Physical Review B, Vol. 43, No. 1, 1991, page 1297, published by The American Physical Society. This magnetoresistive effect element has a structure comprising at least two thin magnetic layers separated by a non-magnetic thin interlayer. Adjacent to one of soft thin magnetic layers is disposed a thin antiferromagnetic layer to provide anti-magnetic force thereto to thereby cause rotation of magnetization therein with an external magnetic field which is different from that of the other soft thin magnetic layer disposed adjacent to the one of soil thin

magnetic layer via a non-magnetic layer. Thus, a change in resistance is caused.

The above mentioned report has suggested, as a practical MR head, a magnetoresistive effect element having a structure comprising a soil magnetic layer, a non-magnetic insulator, a multilayered structure, a non-magnetic insulator and a soft magnetic layer successively deposited in this order. However, the magnetoresistive effect element has problems that regenerated waves have a quite asymmetrical waveform, and that there is a fear that the magnetoresistive effect element may corrode because the magnetoresistive effect element is exposed to an ABS plane. If a magnetoresistive effect element is designed so that it is separated from the ABS plane, and an external magnetic field is introduced to the magnetoresistive effect element through a soft magnetic yoke, the symmetry of regenerated waveforms are considerably improved to thereby eliminate a fear of the corrosion of the magnetoresistive effect element.

SUMMARY OF THE INVENTION

In view of the foregoing problems of prior magnetoresistive effect elements, it is an object of the present invention to provide a magnetoresistive effect element capable of providing the enhancement of regenerated outputs thereof and also improving the symmetry of waveforms of regenerated waves.

In one aspect, the invention provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a thin magnetic layer and a non-magnetic layer at least once successively deposited, one of the magnetic thin layers having a coercive force H_{C2}, and another thin magnetic layer deposited adjacent to the one of the thin magnetic layers through the non-magnetic layer, having a coercive force H_{C3} which is greater than the coercive force H_{C2} ($0<H_{C2}<H_{C3}$), and (b) bias field applying means for applying a bias magnetic field to the artificial lattice multilayered structure, characterized in that the bias magnetic field is applied to the artificial lattice multilayered structure so that an orientation of residual magnetization of the another thin magnetic layer is the same as an orientation of a bias magnetic field to be applied to the artificial lattice multilayered structure.

In another aspect, the invention provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a first thin magnetic layer, a thin non-magnetic layer and a second thin magnetic layer at least once successively deposited in this order, and (b) bias field applying means for applying a bias magnetic field to the artificial lattice multilayered structure, characterized in that the artificial lattice multilayer-

ed structure further comprising a thin antiferromagnetic layer so that the artificial lattice multilayered structure comprises the first thin magnetic layer, the thin non-magnetic layer, the second thin magnetic layer and the thin antiferromagnetic layer at least once successively deposited in this order, and the bias magnetic field is applied to the artificial lattice multilayered structure so that an orientation of magnetization of a thin magnetic layer a bias of which is exchanged by the thin antiferromagnetic layer is the same as an orientation of a bias magnetic field to be applied to the artificial lattice multilayered structure.

In a preferred embodiment, the bias field applying means includes a shunt layer a separation of which cause a magnetic field, the shunt layer being composed of a non-magnetic layer having a thickness ranging from 2 nm to 20 nm both inclusive.

In another preferred embodiment, the bias field applying means includes a permanent magnet for producing a magnetic field, the permanent magnet having a residual magnetic flux density ranging from 1000 G to 5000 G both inclusive.

In still another preferred embodiment, the bias field applying means includes means for generating an induction field by means of an electrical current.

In yet another preferred embodiment, the bias field applying means includes a soft magnetic film which generates a leakage magnetic field.

In still yet another preferred embodiment, the bias field applying means includes means for running a sense current through two of the artificial lattice multilayered structure to thereby generate a bias field.

In still another aspect, the invention also provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a thin magnetic layer and a non-magnetic layer at least once successively deposited at least two times, one of the magnetic thin layers having a coercive force H_{C2}, and another thin magnetic layer deposited adjacent to the one of the thin magnetic layers via the non-magnetic layer, having a coercive force H_{C3} which is greater than the coercive force H_{C2} ($0 < H_{C2} < H_{C3}$), (b) yokes positioned relative to the artificial lattice multilayered structure with a non-magnetic insulating layer disposed between the yokes and the artificial lattice multilayered structure, and (c) means for applying an electrical current to the artificial lattice multilayered structure, characterized in that the electrical current is applied to the artificial lattice multilayered structure so that the electrical current runs in a negative direction of an X axis, the X axis being defined so that a Y axis is defined to be a magnetization orientation when a magnetic field is equal to zero after a magnetization of the another thin magnetic

layer has been saturated, and a Z axis is defined to be a direction from the artificial lattice multilayered structure towards the yokes perpendicularly to the artificial lattice multilayered structure.

In yet another aspect, the invention provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a thin magnetic layer and a non-magnetic layer at least once successively deposited, and (b) yokes disposed relative to the artificial lattice multilayered structure, characterized in that the yokes are overlapped with the artificial lattice multilayered structure at opposite ends of the multilayered structure, an overlapping length of the yokes with the artificial lattice multilayered structure is 2.0 μm or more.

In still yet another aspect, the invention provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a thin magnetic layer and a non-magnetic layer at least once successively deposited, and (b) yokes disposed relative to the artificial lattice multilayered structure, characterized in that the artificial lattice multilayered structure has a magnetoresistive height up to 10 μm inclusive.

In further another aspect, the invention provides a magnetoresistive effect element comprising (a) an artificial lattice multilayered structure comprising a thin magnetic layer and a non-magnetic layer at least once successively deposited, and (b) a ring-shaped yoke positioned relative to the artificial lattice multilayered structure, characterized in that a distance between a surface from which a magnetic field is to be detected and the artificial lattice multilayered structure is greater than a gap depth of the ring-shaped yoke, and the gap depth is up to 5 μm inclusive.

In a preferred embodiment, the multilayered structure further comprising a further magnetic layer and a thin antiferromagnetic layer so that the multilayered structure is composed of a thin magnetic layer, a thin non-magnetic layer, a thin magnetic layer and a thin antiferromagnetic layer at least once successively deposited in this order.

In another preferred embodiment, the multilayered structure further comprising a metallic thin layer so that the multilayered structure is composed of a metallic thin layer, a thin magnetic layer, a thin non-magnetic layer, a thin magnetic layer and a thin antiferromagnetic layer at least once successively deposited in this order.

In the above mentioned magnetoresistive effect layered structure disclosed in Japanese Patent Public Disclosure No. 4-218982, a difference in coercive forces of thin magnetic layers disposed adjacent to each other via a non-magnetic layer causes orientation of magnetization of magnetic layers positioned adjacent to each other by an external magnetic field, to change parallelism to

antiparallelism to thereby cause a change in resistance. In other words, supposing that each of adjacent magnetic layers has a coercive force H_{C2} and H_{C3} ($0<H_{C2}<H_{C3}$), respectively, when an intensity H of an external magnetic field is between the coercive forces H_{C2} and H_{C3} ($H_{C2}<H<H_{C3}$), orientation of magnetization of the adjacent thin magnetic layers become opposite to each other, thereby a resistance is increased. Thus, the magnetization of the thin magnetic layer having a coercive force H_{C3} is to be first saturated in order to cause a magnetoresistive effect element to operate properly.

In addition, in the multilayered structure in question, an exchange bias force is generated by forming a thin antiferromagnetic layer adjacent to one of deposited magnetic layers between which a non-magnetic layer is sandwiched. The thus generated exchange bias force causes orientation of magnetization of adjacent magnetic layers to change from parallelism to antiparallelism to thereby cause a resistance variation. In other words, supposing that a thin magnetic layer a bias of which is exchanged by a thin antiferromagnetic layer has anti-magnetic force Hex and an other thin magnetic layer has a coercive force H_{C2} - ($0<H_{C2}<Hex$), when an external magnetic field has the intensity H intermediate between H_{C2} and Hex ($H_{C2}<H<Hex$), the orientation of magnetization of the adjacent magnetic layers become opposite to each other, thereby a resistance is increased.

In the multilayered structure composed of finely formed artificial lattice, there occurs magnetostatic coupling at ends of the multilayered structure between adjacent thin magnetic layers between which a non-magnetic thin interlayer is sandwiched. Hence, even if an external magnetic field has an intensity of zero, the magnetization of adjacent magnetic layers is caused to be antiparallel to each other at ends of a multilayered structure. That is, the thin magnetic layer having a coercive force H_{C2} has the magnetization distribution in which the magnetization is being gradually saturated from a center of the layer towards ends of the layer in the width-wise direction of finely formed pattern. Thus, the dynamic range to an external magnetic field is rather small at ends of the multilayered structure. This is the reason for asymmetry of regenerated waveforms in a sensor or a magnetic head.

A magnetic thin film having a coercive force H_{C2} has an excessive bias magnetic field at ends thereof due to a thin magnetic layer having a coercive force H_{C3} or a thin magnetic layer a bias of which is exchanged by a thin antiferromagnetic layer. In order to improve this asymmetry, it is preferable to apply a bias magnetic field to the multilayered structure to thereby suppress the influence of magnetostatic coupling in a thin magnetic layer having a coercive force H_{C2}. In such appliance of a bias magnetic field, it is indispensable to cause an orientation of such a bias magnetic field to be the same as an orientation of residual magnetization of a thin magnetic layer having a coercive force H_{C3} or an orientation of magnetization of a thin magnetic layer a bias of which is exchanged by a thin antiferromagnetic layer. A system for applying a bias magnetic field to a magnetoresistive effect element can be selected among a shunt bias system, an induction field system using a current, a permanent magnet bias system, a soil film bias system and an alternate bias system.

The shunt bias system has a non-magnetic conductive layer formed on a multilayered structure. A bias magnetic field is applied to magnetoresistive effect element by a magnetic field generated by a sense current splitting to the non-magnetic conductive layer. This system has advantages that the system has a simple structure and hence can be easily constructed.

In the induction field system, a non-magnetic conductive layer is formed on a multilayered structure with a non-magnetic insulating layer being sandwiched between the layers, and a bias magnetic field is applied to a magnetoresistive effect element by running an electrical current through the non-magnetic conductive layer.

The permanent magnet bias system has one or more permanent magnet(s) disposed in the vicinity of a multilayered structure to thereby apply to a bias magnetic field to a magnetoresistive effect element with a leakage magnetic field leaked from the permanent magnet(s). This system utilizes magnetostatic coupling between a permanent magnet and a multilayered structure to thereby cause a bias magnetic field, and thus can provide a multilayered structure at ends thereof with a bias magnetic field having a greater intensity. As aforementioned, a magnetic thin film having a coercive force H_{C2} has an excessive bias magnetic field at ends thereof due to a thin magnetic layer a bias of which is exchanged by a thin antiferromagnetic layer. Hence, this system is preferable for offsetting the excessive magnetic field.

The soft film bias system utilizes magnetic conjunction of a multilayered structure with a soil magnetic layer disposed adjacent to the multilayered structure. The soft magnetic layer is magnetized by a magnetic field generated by a sense current running through a multilayered structure, and a bias magnetic field is applied to a multilayered structure with a leakage magnetic field leaked from the magnetized soft magnetic layer. This system can provide a large bias field at ends of a multilayered structure, and thus is preferable similarly to the permanent magnet bias system.

The alternate bias system uses two multilayered structures. A bias magnetic field is applied alternately to a magnetoresistive effect element with magnetic fields generated by running a sense current through each of the multilayered structures. This system enables to obtain double outputs or operate a magnetoresistive effect element as a differential element by operating both of the two multilayered structures as a magnetoresistive effect element.

It is possible to use at least two systems among the above mentioned shunt bias system, induction field system permanent magnet system, soft film bias system and alternate bias system.

As aforementioned, even if an external magnetic field has an intensity of zero, the magnetization of adjacent magnetic layers is caused to be antiparallel to each other at ends of a multilayered structure. That is, the thin magnetic layer having a coercive force H_{C2} has the magnetization distribution in which the magnetization is being gradually saturated from a center of the layer towards ends of the layer in the width-wise direction of finely formed pattern. On the other hand, a current field generated by an electrical current running through a multilayered structure considerably affects the magnetization of the thin magnetic layer having a coercive force H_{C2}. In a case of a MR head having a yoke, since a yoke composed of soil magnetic substance is disposed at only one side of a multilayered structure, a magnetic field generated by an electrical current running through a multilayered structure is affected by the yoke to thereby have asymmetrical distribution. The magnetization distribution of a thin magnetic layer having a coercive force H_{C2} is affected by an asymmetric electrical current field to thereby have a difference in dependence on a direction in which an electrical current runs. Thus, the distribution of magnetization orientation of thin magnetic layers disposed adjacent to each other varies in dependence on a direction in which an electrical current runs, thereby there occurs a difference in regenerated outputs.

Hereinbelow will be explained, with reference to Fig. 1, a positional relationship between a multilayered structure and a yoke and also a relationship between an orientation of residual magnetization of a thin magnetic layer having a coercive force H_{C3} and a direction in which an electrical current runs. For simplification, it is supposed that a magnetoresistive effect film is composed of a first thin magnetic layer 2, a non-magnetic layer 4, a second thin magnetic layer 3, and a second thin non-magnetic layer 4 successively deposited three times in this order. The first thin magnetic layer 2 has a coercive forces H_{C2} and the second thin magnetic layer 3 has a coercive force H_{C3} which is greater than the coercive force H_{C2} ($0<H_{C2}<H_{C3}$). It

is now supposed to run an electrical current in a positive or negative direction of a X axis which is defined so that a Y axis is defined to be an orientation of residual magnetization of the second thin magnetic layer 3, and a Z axis is defined to be a direction from the multilayered structure towards yokes 5a and 5b perpendicularly to a surface of the first and second thin magnetic layers 2 and 3. That is, the magnetization of the second thin magnetic layer 3 is oriented in a direction indicated by an arrow A. A width of finely formed pattern of a magnetoresistive effect element corresponds to a magnetoresistive (MR) height as illustrated in Fig. 1. When no electrical current runs through the multilayered structure, the orientation of magnetization of the first and second thin magnetic layers 2 and 3 is antiparallel to each other at ends of the multilayered structure due to magnetostatic coupling. That is, the magnetization of the first thin magnetic layer 2 tends to be directed toward a negative direction of the Y axis. Hence, the magnetization of the first thin magnetic layer 2 is distributed so that the ends thereof have a greater degree of orientation toward a negative direction of the Y axis than the center thereof. Hereinbelow will be explained the magnetization orientation of the first thin magnetic layer 6 located at the center of the plurality of first thin magnetic layers 2.

Supposing that an electrical current is applied in a positive direction of the X axis, a current field generated by an electrical current running through the non-magnetic thin layers 4 disposed closer to the yokes 5a and 5b than the magnetic layer 6 is gathered in the vicinity of the yokes 5a and 5b because the yokes 5a and 5b is composed of magnetic material having high magnetic permeability. On the other hand, a current field generated by an electrical current running through the non-magnetic thin layers 4 disposed farther away from the yoke than the magnetic layer 6 is scarcely affected by the yokes 5a and 5b, and thus the magnetic layer 6 has a greater degree of orientation toward a negative direction of the Y axis at the center thereof. As a result, a variation in magnetization orientation of the magnetic layer 6 relative to a variation of an external magnetic field is suppressed in a negative direction of the Y axis at the center of the multilayered structure which have highest sensitivity to a magnetic field, thereby regenerated outputs are caused to be smaller.

To the contrary, when a current is applied in a negative direction of the X axis, the magnetization at the center of the multilayered structure is distributed so that the magnetization weakens magnetostatic coupling. Thus, comparing to a case in which a current is applied in a positive direction of the X axis, a variation in magnetization of the magnetic layer 6 relative to a variation of an exter-

nal magnetic field is not suppressed, thereby re-generated outputs are amplified. In addition, the symmetry of regenerated waveforms are improved.

The dependency of regenerated outputs on a direction in which a current runs due to the asymmetry of a current field generated because of presence of the yokes 5a and 5b is found only when the magnetic thin layer 2 is sandwiched by the non-magnetic thin layers 4. Thus, the repeat number of deposition in the multilayered structure has to be at least two.

Hereinbelow will be explained as to overlapping length of the multilayered structure and the yoke, and also as to the MR height. In a magnetoresistive effect element having a yoke, a magnet flux generated from a magnetic medium is introduced from the front yoke 5a to the multilayered structure, and then to the rear yoke 5b. As aforementioned, the magnetostatic coupling causes the dynamic range to be smaller at the ends of the multilayered structure relative to a magnetic field generated by the magnetic medium. Hence, it is necessary for considerably enhancing regenerated outputs to prevent a magnetic field having a large intensity from directly entering the ends of the multilayered structure by covering the ends with the yokes 5a and 5b to thereby introduce magnetic flux to the center of the multilayered structure having a large dynamic range. What is required for the enhancement of regenerated outputs is to overlap the multilayered structure with the front and rear yokes 5a and 5b for covering only the ends of the multilayered structure which is affected by magnetostatic coupling. Thus, excessively overlapping disadvantageously results in the deterioration of regenerated outputs. That is, the overlapping lengths L1 and L2 of the multilayered structure with the yokes 5a and 5b have optimal values regardless of the MR height w of the multilayered structure.

If the MR height w is designed to be 10 μm or greater, the leakage of magnetic flux from the multilayered structure occurs remarkably, and hence the multilayered structure is not entirely magnetized efficiently. As a result, regenerated outputs are deteriorated.

On the other hand, the magnetization of the thin magnetic layer 2 having a coercive force H_{C2} is considerably affected by a current field generated by a sense current running through the multilayered structure. For instance, now supposing an artificial lattice structure composed of NiFe, Cu, Co and Cu successively deposited in this order, NiFe has 7 $\mu\Omega \cdot$ cm, Cu has 1.4 $\mu\Omega \cdot$ cm, and Co has 14 $\mu\Omega \cdot$ cm of bulk resistivity at room temperature (RT), and it is considered that a sense current runs mainly through the Cu non-magnetic layer. Herein, supposing that the repeat number N of the deposition in the multilayered structure is three. Even if

there does not exist an external magnetic field, a current field causes the magnetization of the firstly and thirdly deposited magnetic layers is antiparallel to each other. The antiparallelism shows that the firstly and thirdly deposited magnetic layers 2 are difficult to react with an external magnetic field. Supposing that a current density of a sense current running through the multilayered structure is kept constant, as the repeat number N is made greater, the influence of a current field becomes larger, thereby the firstly and lastly deposited magnetic layers 2 are made more difficult to react with an external magnetic field with the result that the regenerated outputs are deteriorated. Thus, the repeat number N is preferable to be five or smaller.

In the case that a magnetoresistive effect element having ring-shaped yokes is to be used, it is possible to reduce the leakage of magnetic flux from the multilayered structure to an lower yoke by setting a distance between a surface from which a magnetic field is to be detected and the multilayered structure to be larger than a gap depth of the ring-shaped yokes. In addition, it is possible to reduce the leakage of magnetic flux from a front yoke to an lower yoke through the gap by setting the gap depth to be 5 μm or shorter.

In accordance with the magnetoresistive effect element explained so far, it is possible to enhance regenerated outputs of the magnetoresistive effect element and further improve the symmetry of waveforms of regenerated waves.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective cross-sectional view illustrating a magnetoresistive effect element.

Fig. 2A is a cross-sectional view illustrating a first embodiment of the magnetoresistive effect element in accordance with the invention.

Fig. 2B is a cross-sectional view illustrating a variation of the first embodiment.

Fig. 3 is a cross-sectional view illustrating a second embodiment of the magnetoresistive effect element in accordance with the invention.

Fig. 4A is a front view illustrating a yoke-type MR head in which is incorporated a magnetoresistive effect element in accordance with the invention.

Fig. 4B is a cross-sectional view taken along the line IV-IV of Fig. 4A.

Fig. 5 is a graph showing the dependency of regenerated outputs and symmetry of regenerated waveforms on a bias field in a shunt bias system.

Fig. 6 is a graph showing the dependency of internal magnetization of the secondly layered thin magnetic layer on a bias field in a shunt bias system.

Fig. 7 is a graph showing the dependency of regenerated outputs and symmetry of regenerated waveforms on a bias field in a permanent magnet bias system.

Fig. 8 is a graph showing the dependency of internal magnetization of the secondly layered thin magnetic layer on a bias field in a permanent magnet bias system.

Fig. 9 is a cross-sectional view illustrating a third embodiment of the magnetoresistive effect element in accordance with the invention.

Fig. 10 is a graph showing the dependency of regenerated outputs and symmetry of regenerated waveforms on a direction in which a current runs.

Fig. 11 is a graph showing the dependency of internal magnetization of the secondly layered thin magnetic layer on a direction in which a current runs.

Fig. 12 is a graph showing the dependency of internal magnetization of the secondly layered thin magnetic layer on a magnetic field derived from a magnetic medium in the case that a current runs in a positive direction of a X axis.

Fig. 13 is a graph showing the dependency of internal magnetization of the secondly layered thin magnetic layer on a magnetic field derived from a magnetic medium in the case that a current runs in a negative direction of a X axis.

Fig. 14 is a graph showing the relationship between regenerated outputs and an overlapping length of a multilayered structure with yokes.

Fig. 15 is a graph showing internal magnetization distribution of the secondly layered thin magnetic layer in the case that a MR height is 5 μm.

Fig. 16 is a graph showing internal magnetization distribution of the secondly layered thin magnetic layer in the case that a MR height is 10 μm.

Fig. 17 is a graph showing the relationship between regenerated outputs and a MR height of a multilayered structure.

Fig. 18 is a graph showing the relationship between regenerated outputs and the repeat number N of deposition of a multilayered structure.

Fig. 19 is a graph showing internal magnetization distribution of the secondly layered thin magnetic layer in the case that the repeat number N is three.

Fig. 20 is a graph showing internal magnetization distribution of the secondly layered thin magnetic layer in the case that the repeat number N is five.

Fig. 21 is a graph showing the relationship between regenerated outputs and a distance between a magnetoresistive effect element and a surface from which a magnetic field is to be detected.

Fig. 22 is a graph showing the relationship between regenerated outputs and a gap depth h of yokes.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments in accordance with the present invention will be explained hereinbelow with reference to drawings.

[Embodiment 1]

Fig. 2A illustrates a first embodiment of the magnetoresistive effect element in which the shunt bias system is adopted. As illustrated, a magnetoresistive effect element 1a is constructed as an artificial lattice magnetoresistive effect element which has a multilayered structure 1A including a thin magnetic layer 2a composed of NiFe and 1.5 nm thick, a thin non-magnetic layer 4a composed of Cu and 3.5 nm thick, a thin magnetic layer 3a composed of Co and 1.5 nm thick, and a thin non-magnetic layer 4a composed of Cu and 3.5 nm thick successively deposited in this order three times. The magnetoresistive effect element 1a has a finely formed pattern width corresponding to MR height as illustrated in Fig. 2A.

It should be noted that a last non-magnetic Cu layer 4a is not formed. The magnetoresistive effect element 1a further includes a non-magnetic conductive layer 7a composed of a thin Cu layer which is positioned adjacent to the thin magnetic layer 2a disposed at an end of the multilayered structure 1A. As shown in Fig. 2A, an X axis is defined so that the orientation B of residual magnetization of the thin magnetic layer 3a is a positive direction of a Y axis, and a direction from the non-magnetic conductive layer 7a to the thin magnetic layer 3a perpendicularly to an end surface of the multilayered structure 1A is a positive direction of a Z axis. By running a sense current in a negative direction 9a of the X axis, it is possible to apply a bias field to the multilayered structure 1A in a positive direction of the Y axis.

Fig. 2B is a variation of the above mentioned first embodiment. As illustrated, a permanent magnet 30 may be used in place of the non-magnetic conductive layer 7a through which a sense current is to run. The permanent magnet 30 also serves to apply a bias field to the multilayered structure 1A.

[Embodiment 2]

Fig. 3 illustrates a second embodiment of the magnetoresistive effect element adopting the shut bias system. As illustrated, a magnetoresistive effect element 1b in accordance with the second embodiment is constructed as an artificial lattice magnetoresistive effect element which has a mul-

tilayered structure 1B including a thin metallic layer 8 composed of Cu and 3 nm thick, a thin magnetic layer 2b composed of NiFe and 5 nm thick, a thin non-magnetic layer 4b composed of Cu and 2.5 nm thick, a thin magnetic layer 3b composed of NiFe and 5 nm thick, and a thin antiferromagnetic layer 18 composed of FeMn and 10 nm thick successively deposited in this order three times. The magnetoresistive effect element 1b has a finely formed pattern width corresponding to MR height as illustrated in Fig. 3.

The magnetoresistive effect element 1b further includes a non-magnetic conductive layer 7b composed of a thin Cu layer which is positioned adjacent to the thin metallic layer 8 disposed at an end of the multilayered structure 1B. As shown in Fig. 3, an X axis is defined so that the orientation C of the thin magnetic layer 3b which is exchanged a bias thereof by the thin antiferromagnetic layer 18 is a positive direction of a Y axis, and a direction from the non-magnetic conductive layer 7b to the multilayered structure 1B perpendicularly to an end surface of the multilayered structure 1B is a positive direction of a Z axis. By running a sense current in a negative direction 9b of the X axis, it is possible to apply a bias field to the multilayered structure 1B in a positive direction of the Y axis.

The measurements of regenerated outputs and waveforms were carried out by using a yoke-type MR head illustrated in Figs. 4A and 4B into which the magnetoresistive effect element 1a or 1b are incorporated. With reference to Figs. 4A and 4B, the yoke-type MR head includes a ferromagnetic substrate 11 which is composed of NiZn ferrite and constructing a back yoke. The ferromagnetic substrate 11 is formed with a recess which is 30 μm wide and 30 μm deep. The recess is filled with non-magnetic insulating material 12 such as glass. On the non-magnetic insulator 12 is formed the magnetoresistive effect element 1a or 1b having the MR height of 10 μm. A pair of yokes 15 and 16 is provided so that they overlap the magnetoresistive effect element 1a or 1b through electrodes 13 and a non-magnetic insulating layer 14. The electrodes 13 are composed of Au and 0.24 μm thick, and the non-magnetic insulating layer 14 is composed of SiO$_2$ and 0.2 μm thick. The yokes 15 and 16 are composed of NiFe and 1 μm thick. The overlapping portion of the magnetoresistive effect element 1a or 1b with the yokes 15 and 16 is 2 μm long.

It should be noted that the non-magnetic insulating layer 14 is omitted in Fig. 4A for making it easy to understand a positional relationship between the magnetoresistive effect element 1a or 1b and the yokes 15 and 16. A record medium 17 is composed of double layers comprising a perpendicular magnetic record layer 17a and an underlying layer 17b. The perpendicular magnetic record layer 17a is 0.1 μm thick, and has a record bit length of 1 μm. The underlying layer 17b is 0.05 μm thick. A spacing between the yoke-type MR head and the record medium 17 is set to be 0.02 μm.

Fig. 5 shows regenerated outputs and symmetry of regenerated waveforms. The regenerated outputs are normalized ones. The intensity of a bias field was controlled by varying a thickness of the non-magnetic conductive layer 7a or 7b. Fig. 5 shows that the symmetry of regenerated waveforms is gradually improved by appliance of a bias field.

Hereinbelow will be explained the results of Fig. 5 from the viewpoint of the distribution of internal magnetization of the magnetoresistive effect element. The following is analysis of the magnetization relative to a change of a signal field due to the two layers deposited medium 17 of the yoke-type head to which the magnetoresistive effect element in accordance with the invention is applied. The analysis was carried out using an integral element method. In this analysis, it is supposed that a variation in an angle formed between the thin magnetic layers 2a or 2b and 3a or 3b disposed at opposite sides of the thin non-magnetic layer 4a or 4b would cause magnetoresistive effect to occur. The resistivity ρ of the thin non-magnetic layer 4a or 4b is calculated based on the following equation (A) in which ρ_0 represents the resistivity when a magnetic field has an intensity of zero and $\Delta\rho$ represents a variation of the resistivity.

$$\rho = \rho_0 - 0.5 \cdot \Delta\rho \cdot \cos\theta \qquad (A)$$

Fig 6 shows internal magnetization of the secondly deposited magnetic layer 10a or 10b (see Figs. 2 and 3) which is one of the thin magnetic layers 2a or 2b with a thickness of the non-magnetic conductive layer 7a or 7b being used as a parameter. There does not exist a magnetic field derived from the record medium 17. The MR height is set to be 3 μm, and the overlapping length of the magnetoresistive effect element 1a or 1b with the yokes 15 and 16 is set to be 1 μm. When a bias field is equal to zero in strength, the magnetization of the thin magnetic layer 10a or 10b is considerably affected at the ends thereof due to the magnetostatic coupling with the thin magnet layer 3a or 3b, and has a distribution in which the magnetization has the orientation opposite to that of the thin magnetic layer 3a or 3b. The magnetization of the thin magnetic layer 10a or 10b is directed in a negative direction even at the center of the multilayered structure 1A or 1B. This is why the center of the multilayered structure 1A or 1B is affected by the magnetostatic coupling because

the magnetoresistive effect element 1a or 1b has a small MR height.

It can be understood that when a bias field is applied to the magnetoresistive effect element, the influence of the magnetostatic coupling is offset as a bias field becomes more intensive. The intensity of the bias field is controlled by controlling a thickness of the non-magnetic conductive layer 7a or 7b. However, it has been found that a thickness of the non-magnetic conductive layer 7a or 7b for obtaining a bias field having a desired intensity may be varied in dependence on the MR height of the magnetoresistive effect element, and that the preferable range of the thickness of the non-magnetic layer conductive 7a or 7b is between 2 nm and 20 nm both inclusive.

Fig. 7 shows regenerated outputs and symmetry of regenerated waveforms in the case that a bias field is applied to a magnetoresistive effect element by means of the permanent magnet bias system. The regenerated outputs are normalized ones. The intensity of a bias field is controlled by varying residual magnetic flux of a permanent magnet(s). It can be understood that the symmetry of regenerated waveforms is gradually improved by appliance of a bias field.

Fig. 8 shows the results of calculation of magnetization of an internal field of the thin magnetic layers by means of the above mentioned magnetization analysis. It can be understood from Fig. 8 that the influence of the magnetostatic coupling is offset by appliance of a bias field, and that the offset is remarkable in particular at the ends of the layer. It has been found that the residual magnetic flux of a permanent magnet(s) for obtaining a bias field having a desired intensity is varied in dependence on the MR height of the magnetoresistive effect element, and that the preferable range thereof is between 1000 G and 5000 G both inclusive.

The results as aforementioned can be found also in the induction field system, soft film bias system and alternate bias system. The above mentioned shunt bias system, the induction field system, the permanent magnet bias system, the soil film bias system and the alternate bias system may be used alone or in combination with each other.

[Embodiment 3]

Fig. 9 illustrates a third embodiment of the magnetoresistive effect element 1c in accordance with the invention. The magnetoresistive effect element 1c has a multilayered structure 21 comprising a thin metallic layer 25, a thin magnetic layer 22, a thin non-magnetic layer 26, a thin magnetic layer 23 and a thin antiferromagnetic layer 24 successively deposited three times. It is now supposed that the thin magnetic layer 23 a bias of which is

exchanged by the thin antiferromagnetic layer 24 has an antimagnetic force Hex and the thin magnetic layer 22 has a coercive force H_{C2} - $(0 < H_{C2} < Hex)$. A Y axis is defined to be an orientation of residual magnetization of the thin magnetic layer 23, and a Z axis is defined to be a direction from the multilayered structure 21 towards yokes 27 and 28 perpendicularly to a surface of the thin magnetic layers 22 and 23. The definition of the Y and Z axes automatically defines a X axis. A sense current is to run through the multilayered structure 21 in a direction of the thus defined X axis. Thus, the magnetization of the thin magnetic layer 23 is oriented in a direction indicated by an arrow 29. The yoke-type magnetoresistive effect element 1c has a finely formed pattern width corresponding to a MR height w. When no current runs through the multilayered structure 21, the orientations of magnetization of the thin magnetic layers 22 and 23 are antiparallel at ends of the multilayered structure 21 due to magnetostatic coupling. In other words, the magnetization of the thin magnetic layer 22 tends to be oriented toward a negative direction of the Y axis, and hence the magnetization of the thin magnetic layer 22 has a magnetization distribution in which the magnetization is oriented toward a negative direction of the Y axis to greater degree at the ends of the multilayered structure 21 than at the center of the multilayered structure 21.

In a magnetoresistive effect element having a yoke, a magnet flux derived from a magnetically recording medium is introduced from a yoke front 27 to a yoke rear 28 through the multilayered structure 21. As aforementioned, the magnetostatic coupling causes the dynamic range relative to a magnetic field generated by the magnetic medium to be smaller at the ends of the multilayered structure 21. Hence, it is necessary for considerably enhancing regenerated outputs to prevent a magnetic field having a large intensity from directly entering the ends of the multilayered structure 21 by covering the ends with the yokes 27 and 28 to thereby introduce a magnetic flux to the center of the multilayered structure having a large dynamic range. What is required for the enhancement of regenerated outputs is to overlap the multilayered structure 21 with the front and rear yokes 27 and 28 for covering only the ends of the multilayered structure 21 which is affected by magnetostatic coupling. Thus, excessively overlapping disadvantageously results in the deterioration of regenerated outputs. That is, the overlapping lengths L1 and L2 of the multilayered structure 21 with the yokes 27 and 28 have optimal values, specifically, L1, L2 $\leq$ 2.0 μm, regardless of the MR height w of the multilayered structure 21.

If the MR height w is designed to be 10 μm or greater, the remarkable leakage of magnetic flux

from the multilayered structure 21 occurs, and hence the whole multilayered structure 21 is not efficiently magnetized. As a result, regenerated outputs are deteriorated.

In this embodiment, the repeat number N of deposition of layers 25, 22, 26, 23 and 24 is three. However, as mentioned earlier, the repeat number N is preferable to be five or less.

Fig. 10 shows the dependency of regenerated outputs and symmetry of regenerated waveforms on a direction in which an electrical current runs. It can be understood that when a current is to run in a negative direction of the X axis, the significant enhancement of regenerated outputs and the improvement of the symmetry of generated waveforms can be obtained in comparison with a case wherein a current is to run in a positive direction of the X axis.

Hereinbelow will be explained the above mentioned results from the viewpoint of the distribution of internal magnetization of the magnetoresistive effect element. The following is analysis of the magnetization relative to a variation of a signal field due to the two layers deposited medium 17 of the yoke-type MR head to which the magnetoresistive effect element in accordance with the invention is applied. The analysis was carried out using an integral element method. In this analysis, it is supposed that a current runs only through the thin non-magnetic layer 26 at a current density of 1×10^7 A/cm^2, and that a change in an angle formed between the thin magnetic layers 22 and 23 disposed at opposite sides of the thin non-magnetic layer 26 would cause magnetoresistive effect to occur. The resistivity ρ of the thin non-magnetic layer 26 is calculated based on the earlier mentioned equation (A) in which ρ_0 represents the resistivity when a magnetic field has an intensity of zero and $\Delta\rho$ represents a variation of the resistivity.

$$\rho = \rho_0 - 0.5 \cdot \Delta\rho \cdot \cos\theta \qquad (A)$$

Fig. 11 shows the dependency of the internal magnetization of the thin magnetic layer 22a on a direction in which a current runs in the case that a magnetic field derived from the record medium 17 is zero. The MR height is 3 μm, and the overlapping length of the multilayered structure 21 with the yokes 27 and 28 is 1 μm. It can be understood that the magnetization is distributed in such a way that the magnetization at the ends of the thin magnetic NiFe layer 22a has an orientation opposite to that of the thin magnetic layer 23 due to the magnetostatic coupling of the thin magnetic layer 22a with the magnetic layer 23.

When a current runs in a positive direction of the X axis, a current field generated by a current running through the thin non-magnetic layers 26

located closer to the yokes 27 and 28 than the thin magnetic layer 22a is gathered to the yokes, and hence the distribution of magnetization of the thin magnetic layer 22a is shifted to be positive in an area at which the multilayered structure 21 overlaps the yokes 27 and 28. On the other hand, a current field generated by a current running through the thin non-magnetic layers 26 located farther away from the yokes 27 and 28 than the thin magnetic layer 22a is scarcely affected by the yokes 27 and 28. Hence, a current field distribution at opposite sides of the thin magnetic layer 22a becomes asymmetrical, and a magnetization distribution in the vicinity of the center of the thin magnetic layer 22a is shifted to be negative.

When a current runs in a negative direction of the X axis, the magnetization distribution becomes tortuous in a direction opposite to that of the case wherein a current runs in a positive direction of the X axis. As a result, as shown in Fig. 12, in the case that a current runs in a positive direction of the X axis, the magnetization is saturated, when a magnetic field derived from the record medium is minimum, in the vicinity of the center of the thin magnetic layer 22a having the highest sensitivity to a magnetic field, thereby regenerated outputs are suppressed. On the other hand, as shown in Fig. 13, it can be understood that in the case that a current runs in a negative direction of the X axis, a variation of magnetization can be sufficiently detected.

Fig. 14 shows a relationship between the overlapping length of the multilayered structure 21 with the yokes 27 and 28 and the regenerated outputs in the case of the MR height in the third embodiment is set to be 5 μm and 10 μm. The regenerated outputs are normalized as one obtained when the overlapping length is zero. It can be understood from Fig. 14 that the overlapping length at which the regenerated output is maximum is located between 1.0 μm and 1.5 μm in both cases wherein the MR height is 5 μm or 10 μm. Even when the MR height is not 5 μm and 10 μm but other value, the overlapping length L1, L2 at which the regenerated output is maximum is denoted with the following equations.

$$0 < L1 \leq 2.0\mu m \quad 0 < L2 \leq 2.0 \ \mu m$$

Hereinbelow will be explained the above mentioned results from the viewpoint of the distribution of internal magnetization of the magnetoresistive effect element. The following is analysis of the magnetization relative to a variation of a signal field due to the two layers deposited medium 17 of the yoke-type MR head to which the magnetoresistive effect element 1c in accordance with the invention is applied. The analysis was carried out using an

integral element method. In this analysis, it is supposed that a sense current runs only through the thin non-magnetic Cu layer 26 at a current density of 1×10^7 A/cm^2. Figs. 15 and 16 shows the distribution of internal magnetization in a second magnetic layer 22a in a MR height-wise direction in the case that the MR height is 5 μm and 10 μm, respectively. The repeat number N of deposition is three, and the overlapping length of the multilayered structure 21 with the yokes 27 and 28 is 1 μm. It can be understood that the magnetization is distributed in such a way that the magnetization at the ends of the thin magnetic layer 22a has an orientation opposite to that of the thin magnetic layer 23 due to the magnetostatic coupling of the thin magnetic layer 22a with the magnetic layer 23. Thus, the dynamic range to an external magnetic field in a negative direction of the Y axis is quite small. The length of the ends of the multilayered structure subject to the magnetostatic coupling remains almost the same in the cases of 5 μm and 10 μm of the MR height. Accordingly, it can be understood that an external magnetic field derived from a magnetic medium is slightly affected by the magnetostatic coupling and thus introduced to the center of the multilayered structure having a large dynamic range by covering the ends of the multilayered structure with the yokes, thereby it is possible to efficiently magnetize the multilayered structure.

Fig. 17 shows a relationship between the MR height of the multilayered structure and the regenerated outputs. It can be understood that the remarkable leakage of magnetic flux occurs from the multilayered structure to thereby cause the regenerated outputs to be reduced, when the MR height is 10 μm or more. Accordingly, the MR height is preferable to be 10 μm or less.

Fig. 18 shows a relationship between the repeat number N of deposition and the regenerated outputs. It can be understood that the regenerated outputs are decreased in inverse proportion to the repeat number N. Hereinbelow will be explained this relationship. Figs. 19 and 20 show the distribution of internal magnetization in each of the thin magnetic layers 22 in the case of the repeat number N being equal to three and five, respectively. An external magnetic field derived from the magnetic record medium is zero, the MR height of the multilayered structure 21 is 3 μm, and the overlapping length of the multilayered structure 21 with the yokes 27, 28 is 1 μm. With reference to Fig. 19 showing the case that the repeat number N is three, it can be understood that the firstly and thirdly layered magnetic layers 22 are caused by a sense current field to have oppositely directed orientation. In particular, the magnetization of the firstly layered magnetic layer 22 is saturated in a

negative direction of the Y axis entirely in a MR height-wise direction. This shows the magnetization of the firstly layered magnetic layer 22 cannot be rotated when an external magnetic field derived from the magnetic medium is oriented in a negative direction of the Y axis. On the other hand, in the case that the repeat number N is five, both of the firstly and secondly layered magnetic layers 22 are saturated in a negative direction of the Y axis. Hence, it can be understood that there are increased magnetic layers which cannot magnetically rotate in response to an external magnetic field derived from the magnetic record medium.

As aforementioned, the greater repeat number N causes the dynamic range to be smaller with the result of the deterioration of the regenerated outputs. Thus, the repeat number N of deposition is preferable to be five or less.

The above mentioned third embodiment is constructed as a yoke-type magnetoresistive effect element, however, it is possible to construct a magnetoresistive effect element as one with a ring-shaped yokes, having a structure as illustrated in Figs. 4A and 4B. In the magnetoresistive effect element having a ring-shaped yokes, it is possible to reduce the leakage of magnetic flux from the magnetoresistive effect element 1c to the ferromagnetic substrate 11 by setting a distance between a surface from which a magnetic field is to be detected and the multilayered structure to be longer than a gap depth h as defined in Figs. 4A and 4B. In addition, the gap depth h shorter than 5 μm makes it possible to reduce the leakage of magnetic flux from the front yoke 15 to the ferromagnetic substrate 11 through the gap.

Fig. 21 shows a relationship between regenerated outputs and a distance between the surface from which a magnetic field is to be detected and the multilayered structure in the case that the gap depth h is 3 μm. It can be understood that it is possible to enhance the regenerated outputs by setting the distance mentioned above to be longer than the gap depth h.

Fig. 22 shows a relationship between regenerated outputs and a gap depth h. It can be understood that the regenerated outputs are considerably dependent on the gap depth h, and that the regenerated outputs are increased when the gap depth h is 5 μm or less.

It should be noted that the multilayered structure 1A, 1B or 21 in the preferred embodiments mentioned earlier may be formed so that (a) a thin magnetic layer, a thin non-magnetic layer, a thin magnetic layer and a thin non-magnetic layer are at least once successively deposited in this order, (b) a thin magnetic layer, a thin non-magnetic layer, a thin magnetic layer and a thin antiferromagnetic layer are at least once successively deposited

in this order, or (c) a thin metallic layer, a thin magnetic layer, a thin non-magnetic layer, a thin magnetic layer and a thin antiferromagnetic layer are at least once successively deposited in this order.

Claims

1. A magnetoresistive effect element (1a) comprising (a) an artificial lattice multilayered structure (1A) comprising a thin magnetic layer (2a, 3a) and a non-magnetic layer (4a) at least once successively deposited, one of the magnetic thin layers (2a) having a coercive force H_{C2}, and another thin magnetic layer (3a) deposited adjacent to the one (2a) of the thin magnetic layers through the non-magnetic layer (4a), having a coercive force H_{C3} which is greater than the coercive force H_{C2} - ($0 < H_{C2} < H_{C3}$), and (b) bias field applying means for applying a bias magnetic field to the artificial lattice multilayered structure (1A), characterized in that

   the bias magnetic field is applied to the artificial lattice multilayered structure (1A) so that an orientation of residual magnetization of the another thin magnetic layer (3a) is the same as an orientation of a bias magnetic field to be applied to the artificial lattice multilayered structure (1A).

2. A magnetoresistive effect element (1b) comprising (a) an artificial lattice multilayered structure (1B) comprising a first thin magnetic layer (2b), a thin non-magnetic layer (4b) and a second thin magnetic layer (3b) at least once successively deposited in this order, and (b) bias field applying means for applying a bias magnetic field to the artificial lattice multilayered structure (1B), characterized in that

   the artificial lattice multilayered structure (1B) further comprising a thin antiferromagnetic layer (18) so that the artificial lattice multilayered structure (1B) comprises the first thin magnetic layer (2b), the thin non-magnetic layer (4b), the second thin magnetic layer (3b) and the thin antiferromagnetic layer (18) at least once successively deposited in this order, and
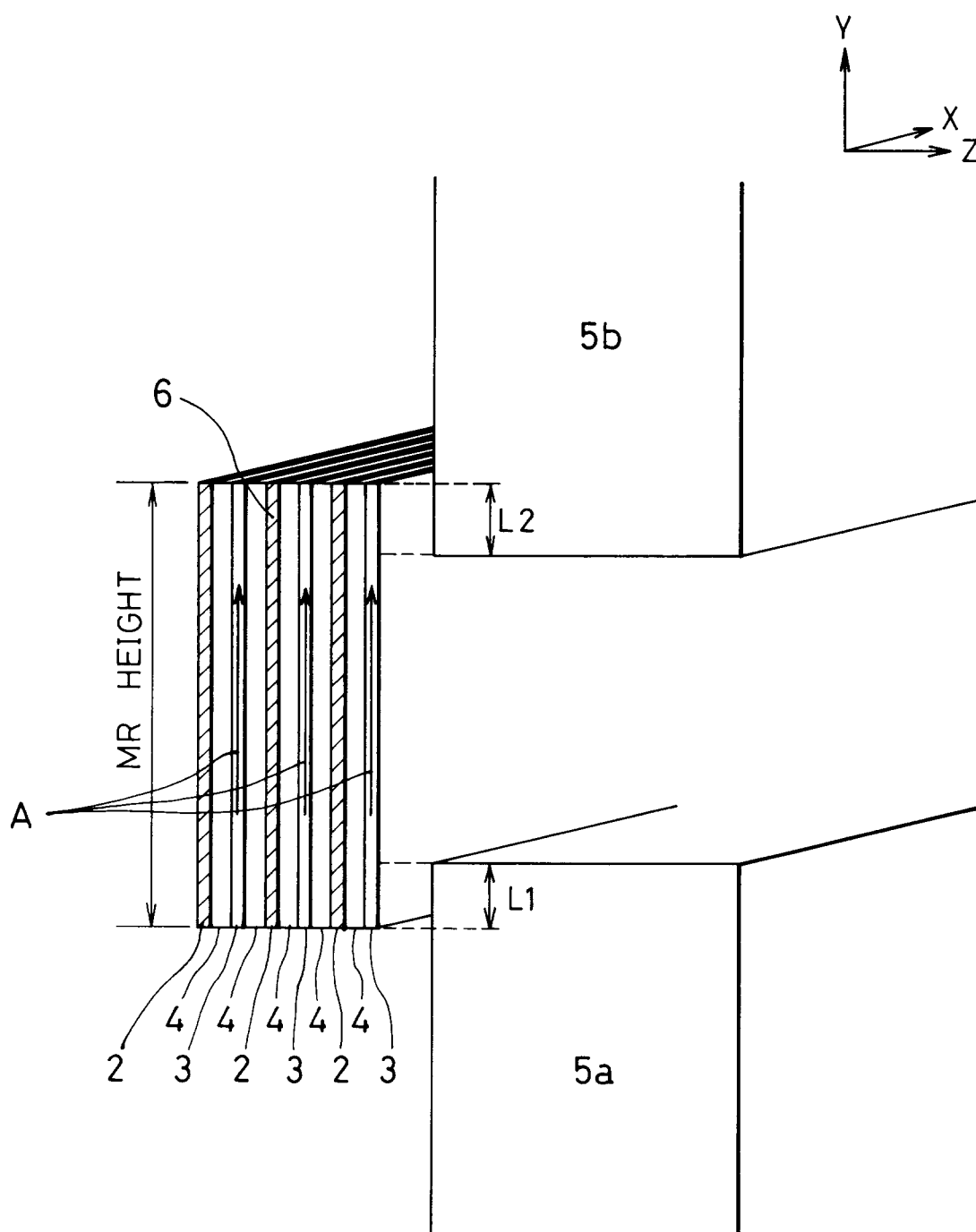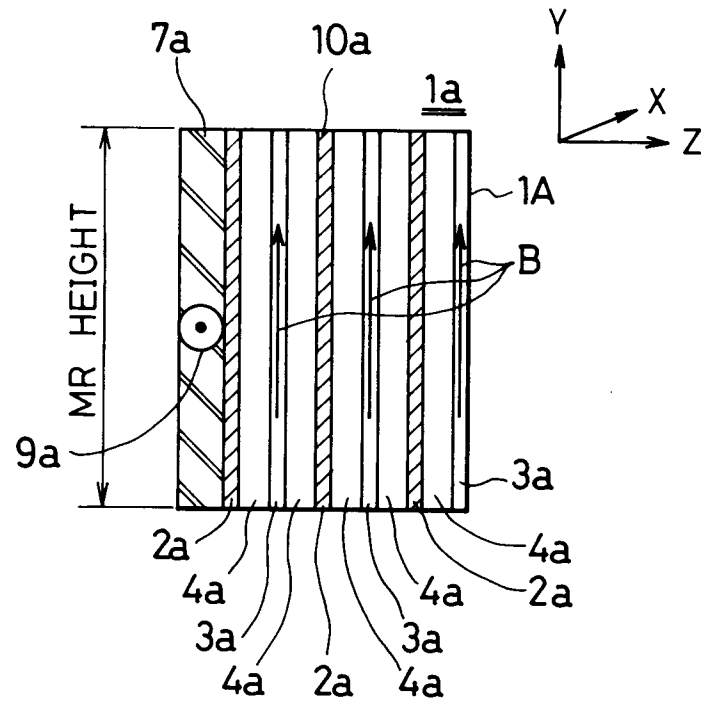
   the bias magnetic field is applied to the artificial lattice multilayered structure (1B) so that an orientation of magnetization of a thin magnetic layer a bias of which is exchanged by the thin antiferromagnetic layer (18) is the same as an orientation of a bias magnetic field to be applied to the artificial lattice multilayered structure (1B).

3. The magnetoresistive effect element (1a, 1b) as recited in claim 1 or 2, wherein the bias field applying means includes a shunt layer (7a) a separation of which cause a magnetic field, the shunt layer (7a) being composed of a nonmagnetic layer having a thickness ranging from 2 nm to 20 nm both inclusive.

4. The magnetoresistive effect element (1a, 1b) as recited in claim 1 or 2, wherein the bias field applying means includes a permanent magnet for producing a magnetic field, the permanent magnet having a residual magnetic flux density ranging from 1000 G to 5000 G both inclusive.

5. The magnetoresistive effect element (1a, 1b) as recited in claim 1 or 2, wherein the bias field applying means includes means for generating an induction field by means of an electrical current.

6. The magnetoresistive effect element (1a, 1b) as recited in claim 1 or 2, wherein the bias field applying means includes a soft magnetic film which generates a leakage magnetic field.

7. The magnetoresistive effect element (1a, 1b) as recited in claim 1 or 2, wherein the bias field applying means includes means for running a sense current through two of the artificial lattice multilayered structure to thereby generate a bias field.

8. A magnetoresistive effect element (1a, 1b, 1c) comprising (a) an artificial lattice multilayered structure (1A, 1B, 21) comprising a thin magnetic layer (2a, 3a, 2b, 3b, 22, 23) and a non-magnetic layer (4a, 4b, 26) at least once successively deposited at least two times, one of the magnetic thin layers (2a, 2b, 22) having a coercive force H_{C2}, and another thin magnetic layer (3a, 3b, 23) deposited adjacent to the one (2a, 2b, 22) of the thin magnetic layers via the non-magnetic layer (4a, 4b, 26), having a coercive force H_{C3} which is greater than the coercive force H_{C2} ($0 < H_{C2} < H_{C3}$), (b) yokes (15, 16, 27, 28) positioned relative to the artificial lattice multilayered structure (1A, 1B, 21) with a non-magnetic insulating layer (12) disposed between the yokes (15, 16, 27, 28) and the artificial lattice multilayered structure (1A, 1B, 21), and (c) means for applying an electrical current to the artificial lattice multilayered structure (1A, 1B, 21), characterized in that

   the electrical current is applied to the artificial lattice multilayered structure (1A, 1B, 21) so that the electrical current runs in a negative

direction of an X axis, the X axis being defined so that a Y axis is defined to be a magnetization orientation when a magnetic field is equal to zero after a magnetization of the another thin magnetic layer (3a) has been saturated, and a Z axis is defined to be a direction from the artificial lattice multilayered structure (1A, 1B, 21) towards the yokes (15, 16, 27, 28) perpendicularly to the artificial lattice multilayered structure (1A, 1B, 21).

9. A magnetoresistive effect element (1a, 1b, 1c) comprising (a) an artificial lattice multilayered structure (1A, 1B, 21) comprising a thin magnetic layer (2a, 2b, 22, 3a, 3b, 23) and a non-magnetic layer (4a, 4b, 26) at least once successively deposited, and (b) yokes (15, 16, 27, 28) disposed relative to the artificial lattice multilayered structure (1A, 1B, 21), characterized in that

the yokes (15, 16, 27, 28) are overlapped with the artificial lattice multilayered structure (1A, 1B, 21) at opposite ends of the multilayered structure (1A, 1B, 21), an overlapping length of the yokes (15, 16, 27, 28) with the artificial lattice multilayered structure (1A, 1B, 21) is 2.0 μm or more.

10. A magnetoresistive effect element (1a, 1b, 1c) comprising (a) an artificial lattice multilayered structure (1A, 1B, 21) comprising a thin magnetic layer (2a, 2b, 22, 3a, 3b, 23) and a non-magnetic layer (4a, 4b, 26) at least once successively deposited, and (b) yokes (15, 16, 27, 28) disposed relative to the artificial lattice multilayered structure (1A, 1B, 21), characterized in that

the artificial lattice multilayered structure (1A, 1B, 21) has a magnetoresistive height up to 10 μm inclusive.

11. A magnetoresistive effect element (1a, 1b, 1c) comprising (a) an artificial lattice multilayered structure (1A, 1B, 21) comprising a thin magnetic layer (2a, 2b, 22, 3a, 3b, 23) and a non-magnetic layer (4a, 4b, 26) at least once successively deposited, and (b) a ring-shaped yoke (15, 16) positioned relative to the artificial lattice multilayered structure (1A, 1B, 21), characterized in that

a distance between a surface from which a magnetic field is to be detected and the artificial lattice multilayered structure (1A, 1B, 21) is greater than a gap depth of the ring-shaped yoke (15, 16), and the gap depth is up to 5 μm inclusive.

12. The magnetoresistive effect element (1b, 1c) as recited in any of the claims 8 to 11, wherein the multilayered structure (1B, 21) further comprising a further magnetic layer (3b) and a thin antiferromagnetic layer (18) so that the multilayered structure (1B, 21) is composed of a thin magnetic layer (2b), a thin non-magnetic layer (4b), a thin magnetic layer (3b) and a thin antiferromagnetic layer (18) at least once successively deposited in this order.
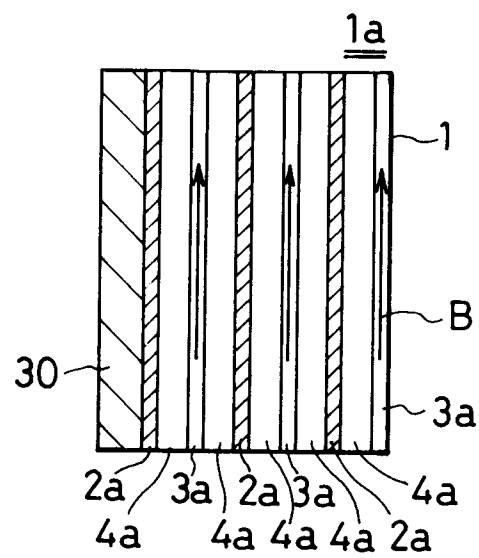
13. The magnetoresistive effect element (1b, 1c) as recited in claim 12, wherein the multilayered structure (1B, 21) further comprising a metallic thin layer (8, 25) so that the multilayered structure (1B, 21) is composed of a metallic thin layer (8), a thin magnetic layer (2b), a thin non-magnetic layer (4b), a thin magnetic layer (3b) and a thin antiferromagnetic layer (18) at least once successively deposited in this order.
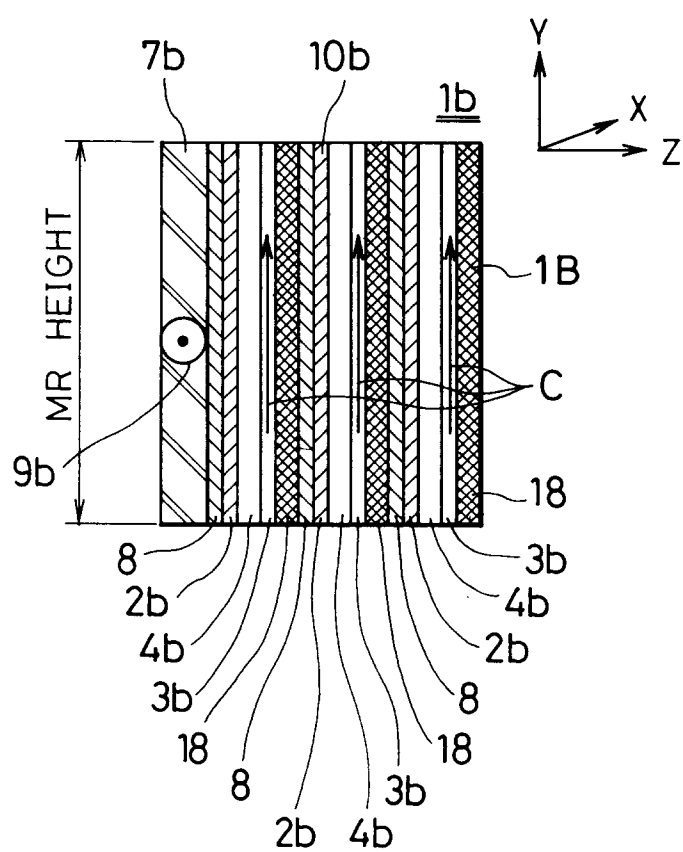
FIG. 1

F I G. 2A

F I G. 2B

F I G . 3

F I G . 4 A
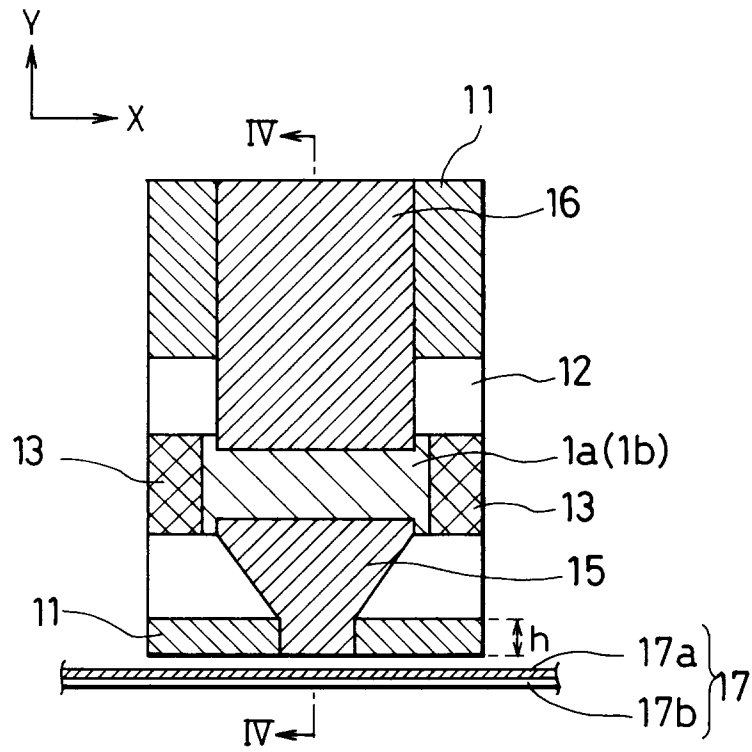
F I G . 4 B
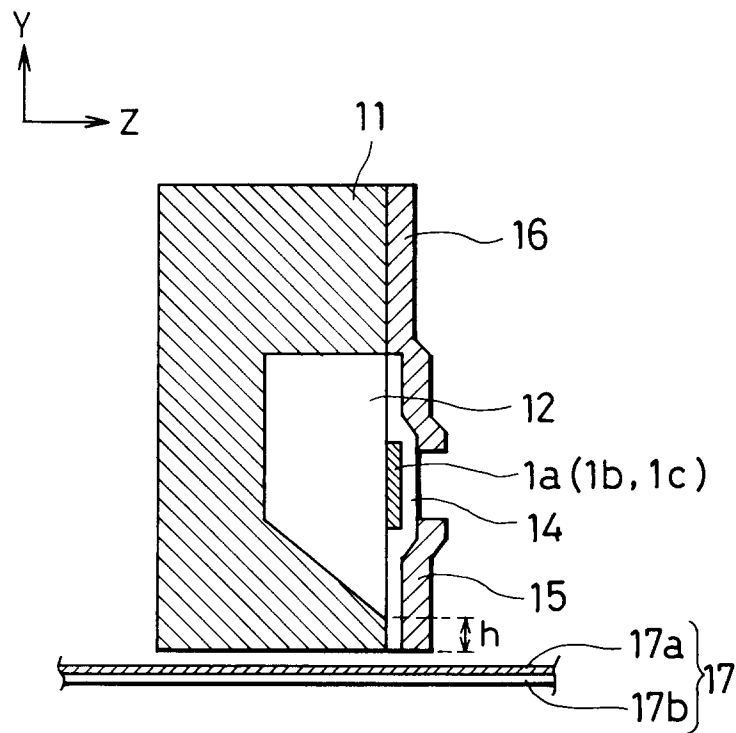
FIG.5
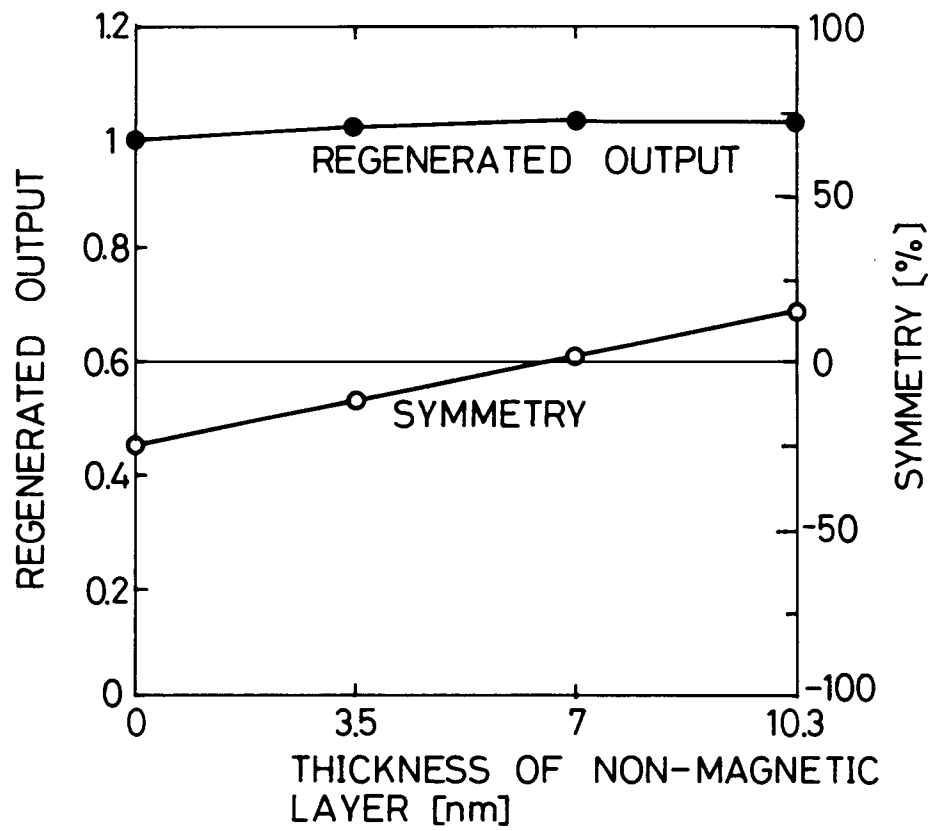
FIG.6
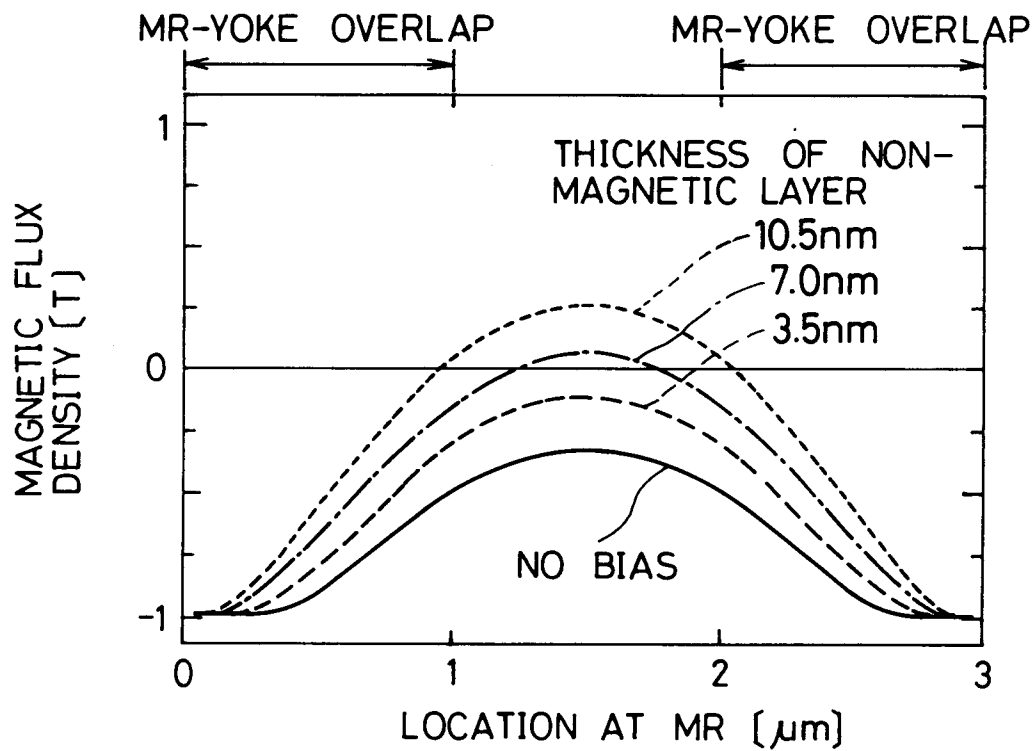
F I G . 7
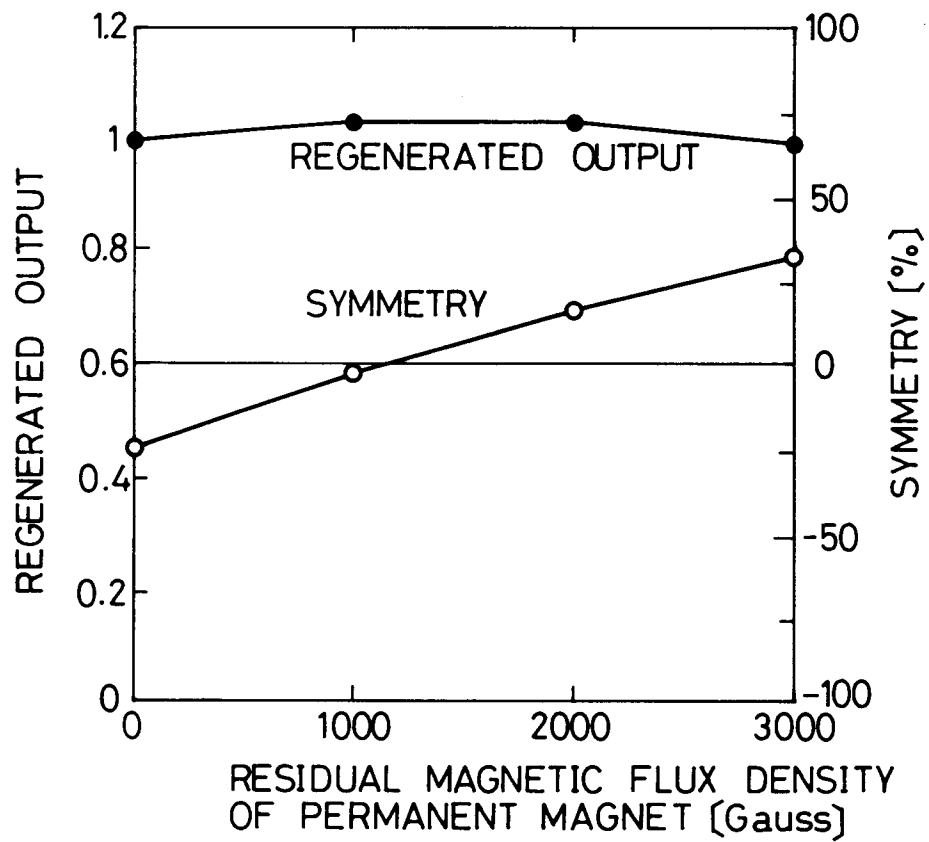
F I G . 8

FIG.9

F I G . 10

F I G . 11

FIG. 12

MR-YOKE OVERLAP MR-YOKE OVERLAP

POSITIVE DIRECTION

MAXIMUM FIELD
ZERO FIELD
MINIMUM FIELD

MAGNETIC FLUX DENSITY [T]

LOCATION AT MR [μm]

FIG. 13

MR-YOKE OVERLAP MR-YOKE OVERLAP

NEGATIVE DIRECTION

MAXIMUM FIELD
ZERO FIELD
MINIMUM FIELD

MAGNETIC FLUX DENSITY [T]

LOCATION AT MR [μm]
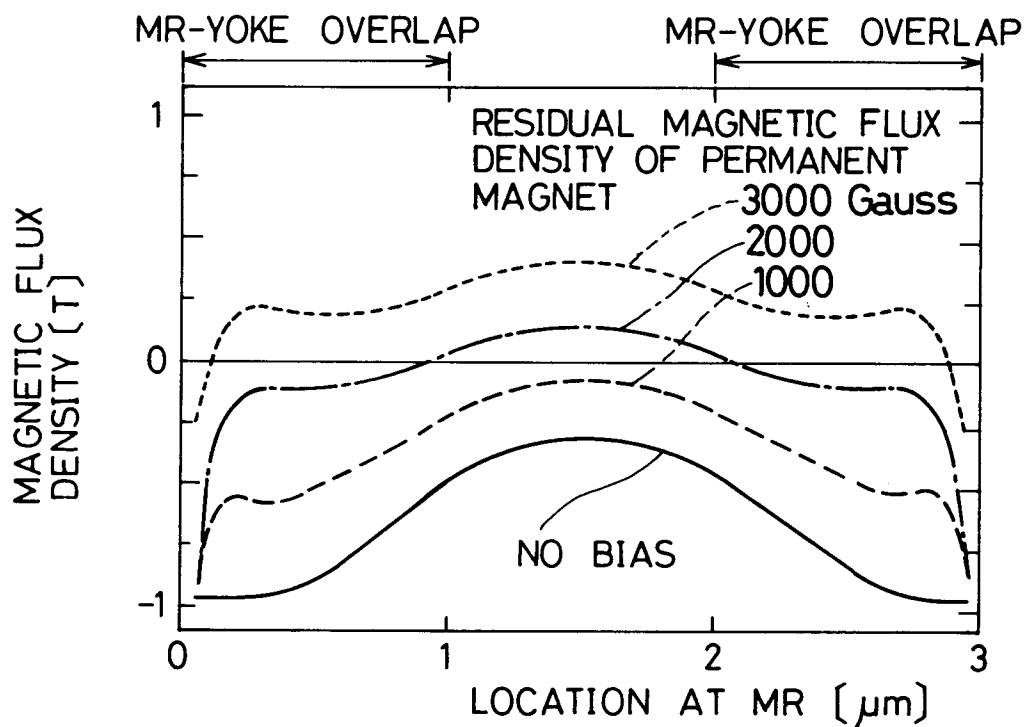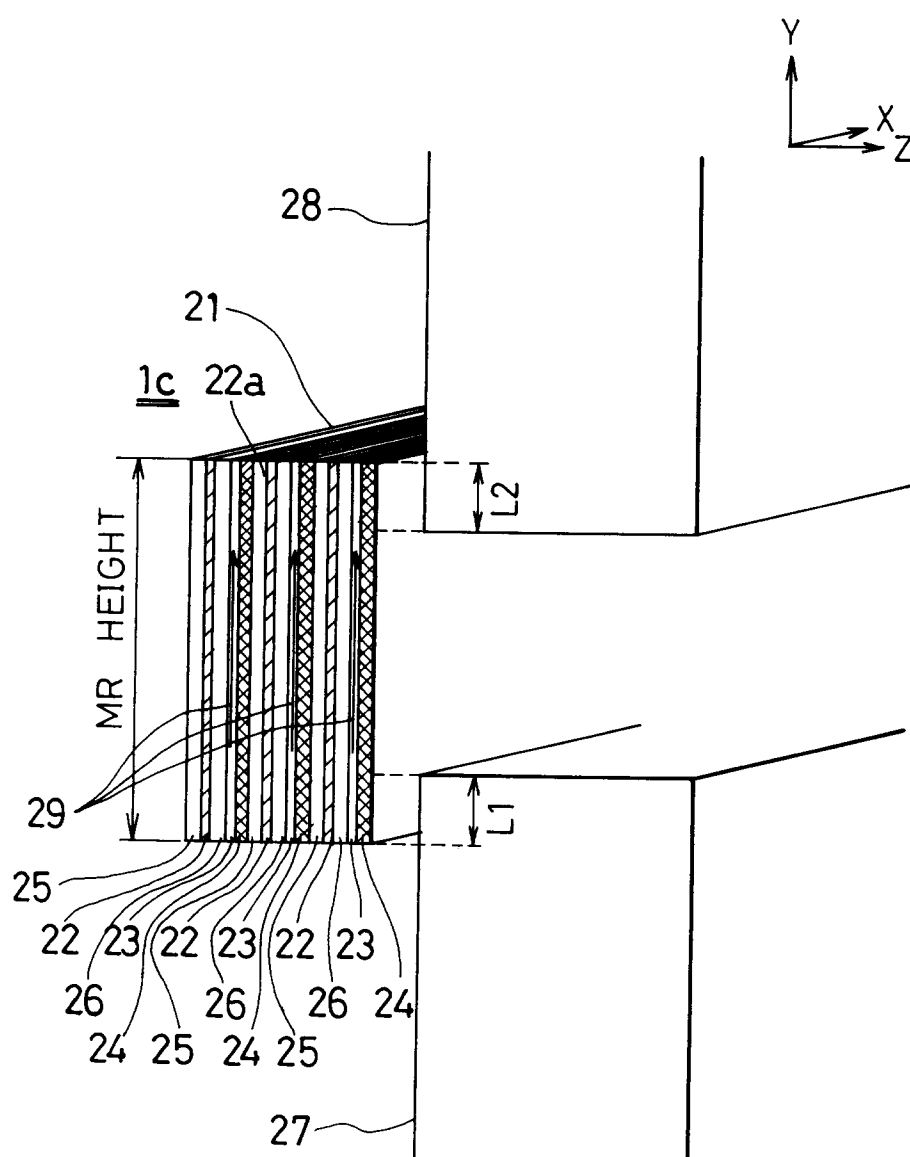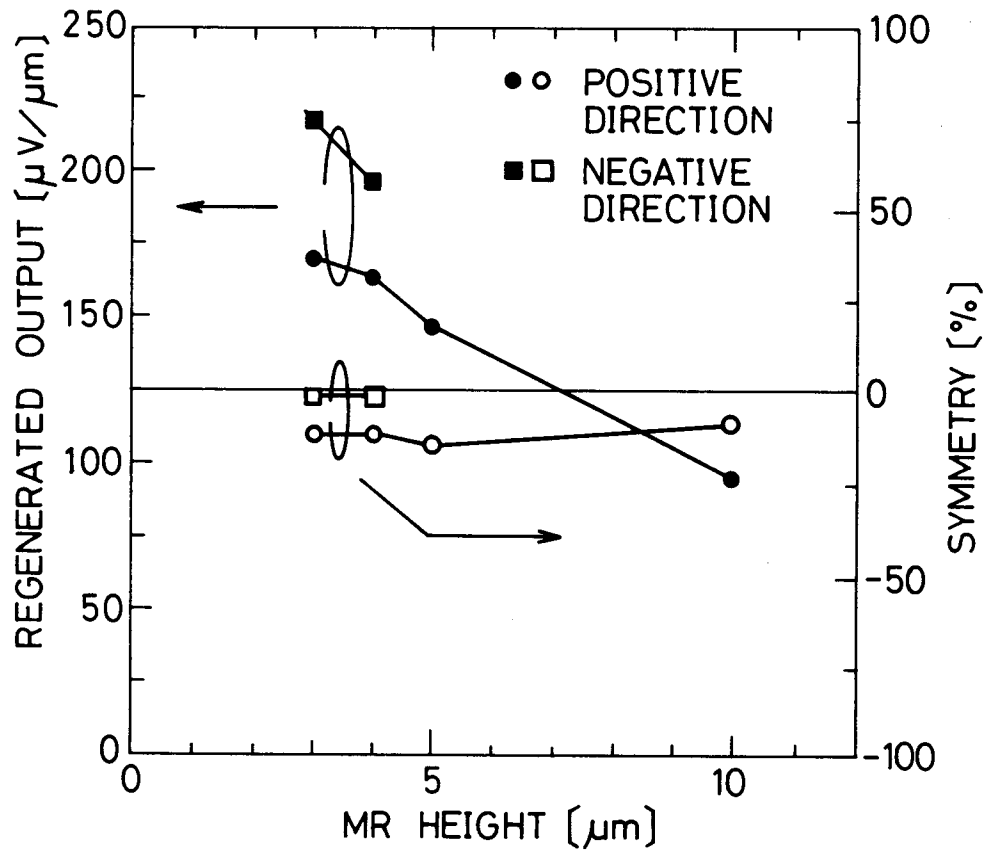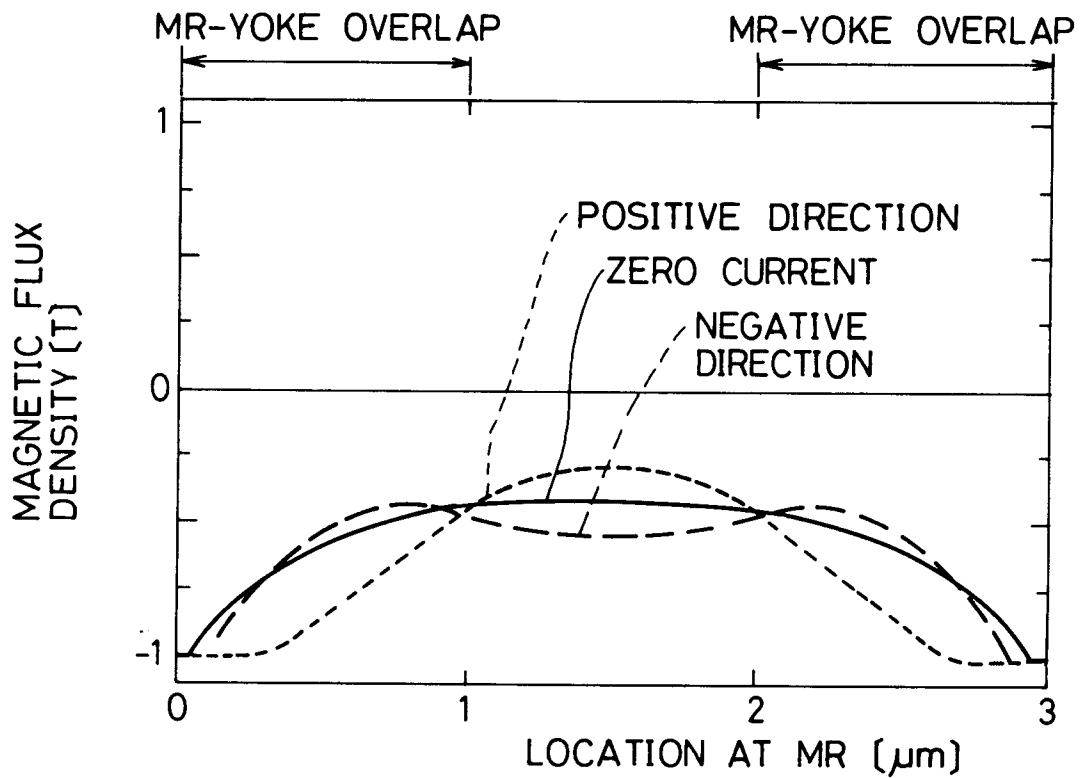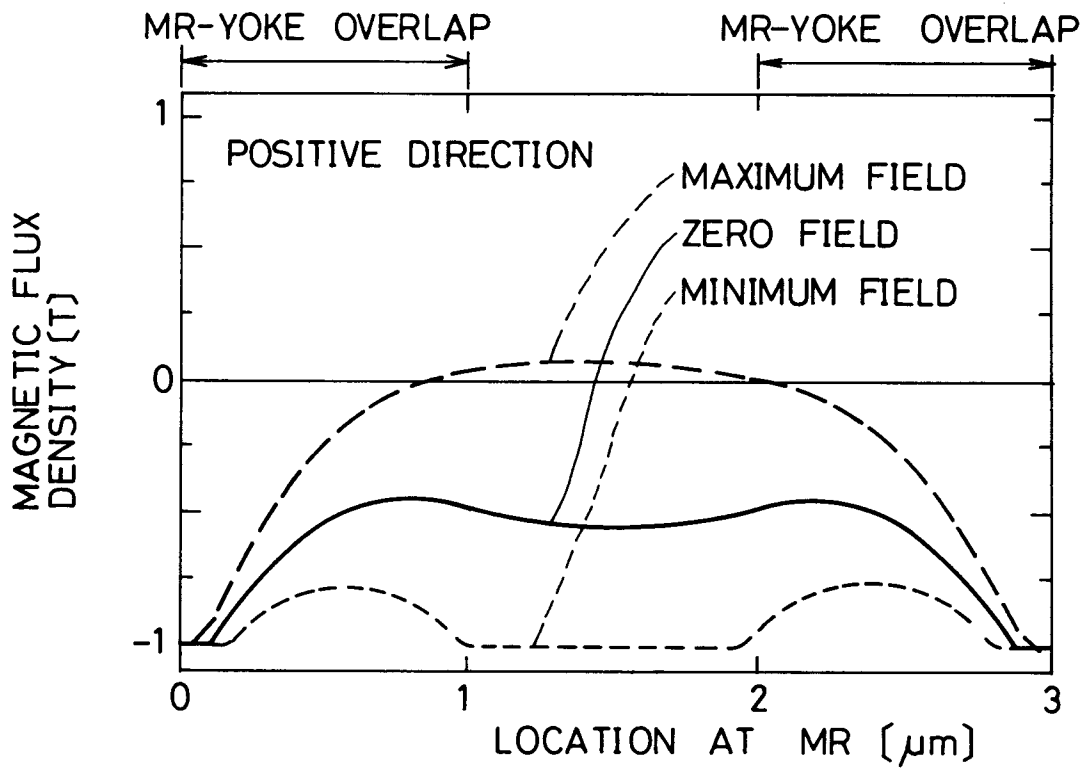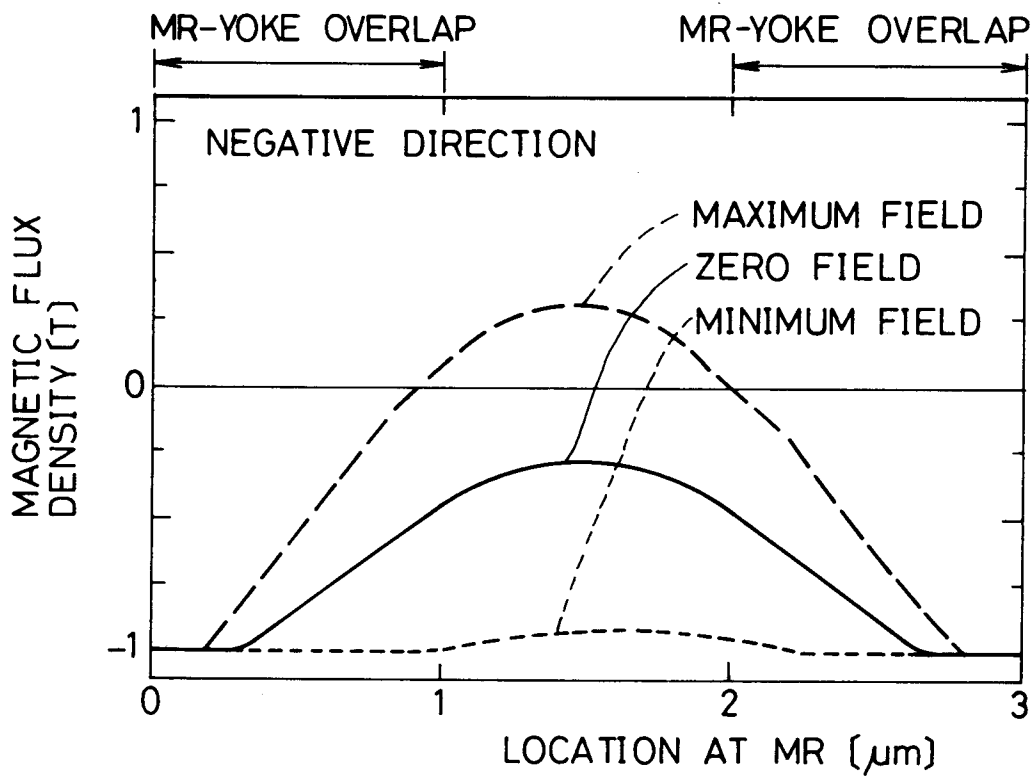
FIG. 14
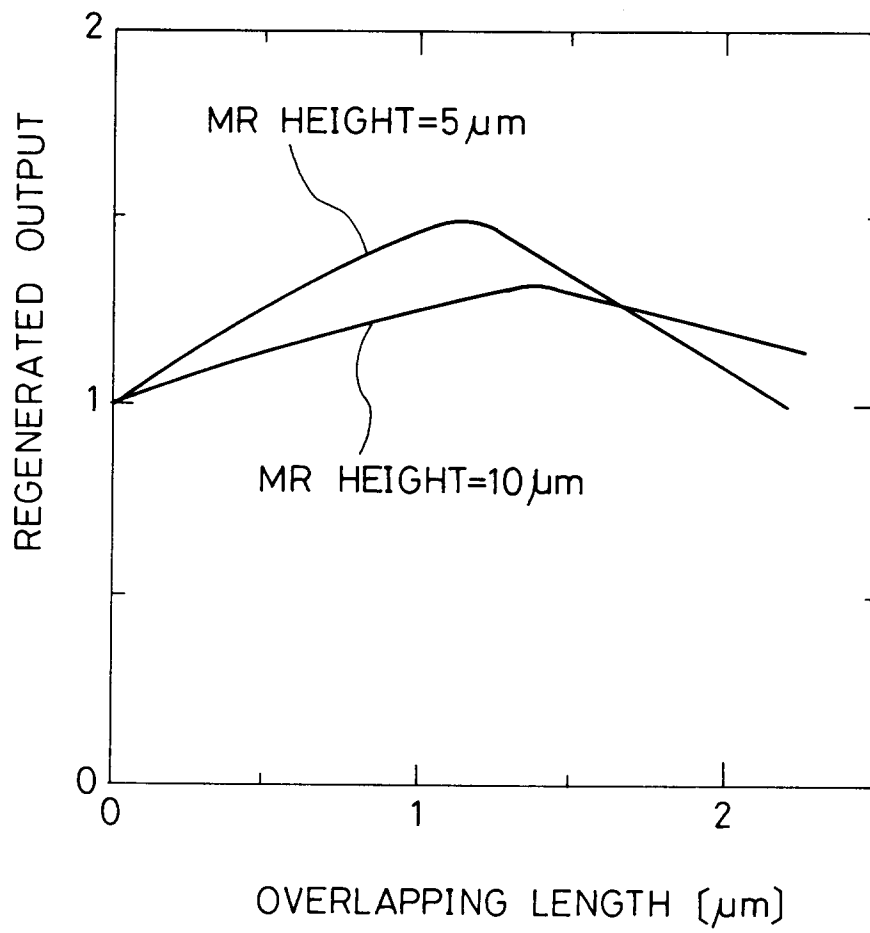
FIG. 15

FIG. 16

FIG. 17

FIG. 18
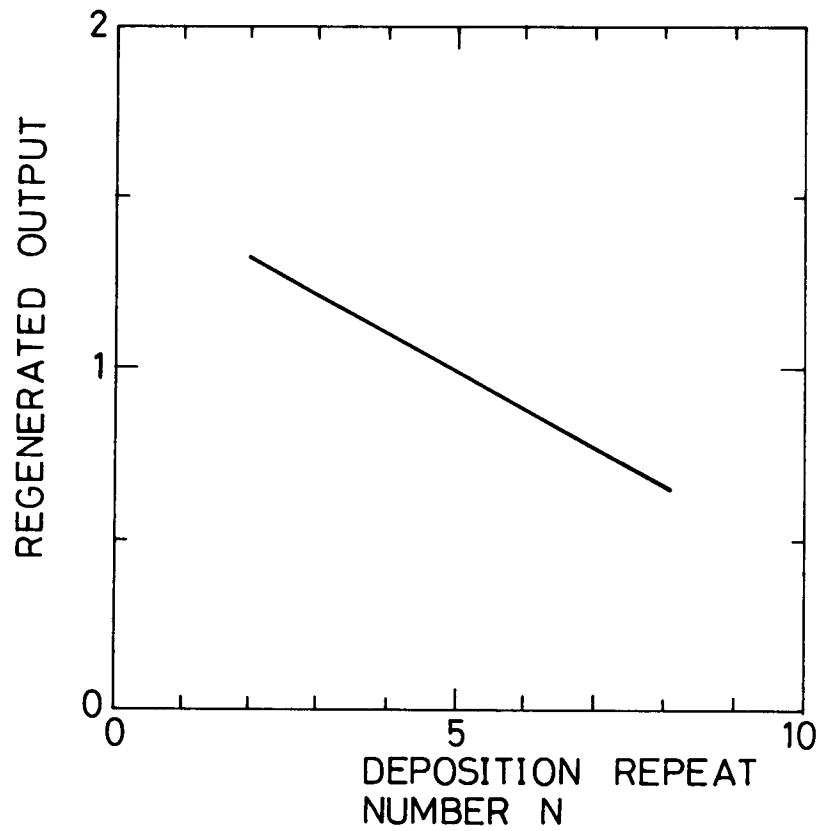
FIG.19
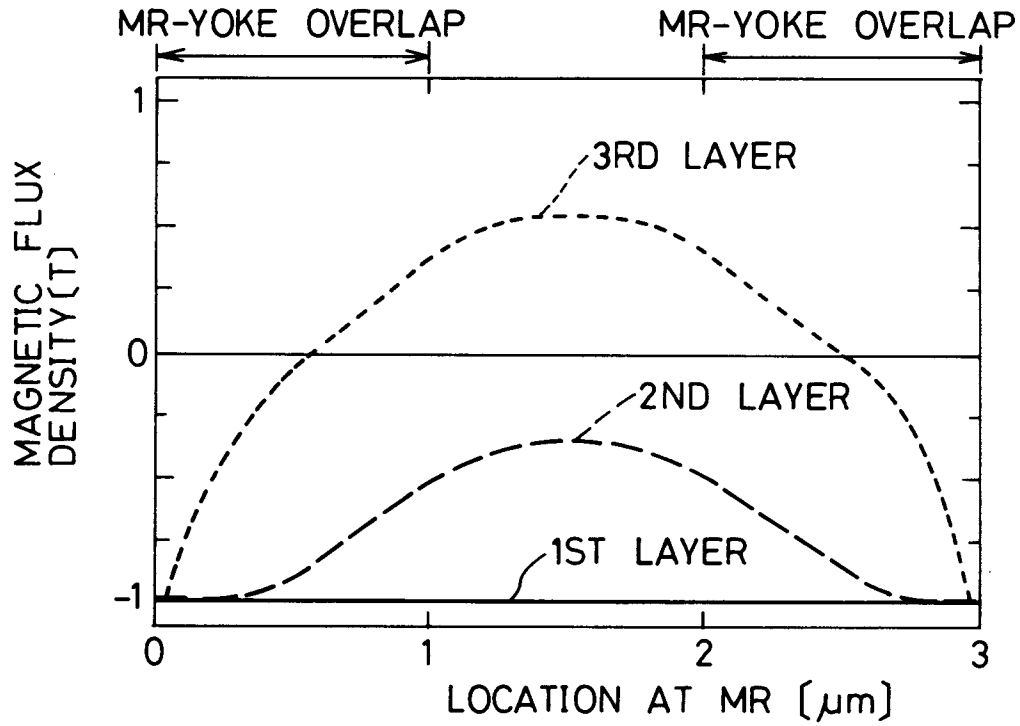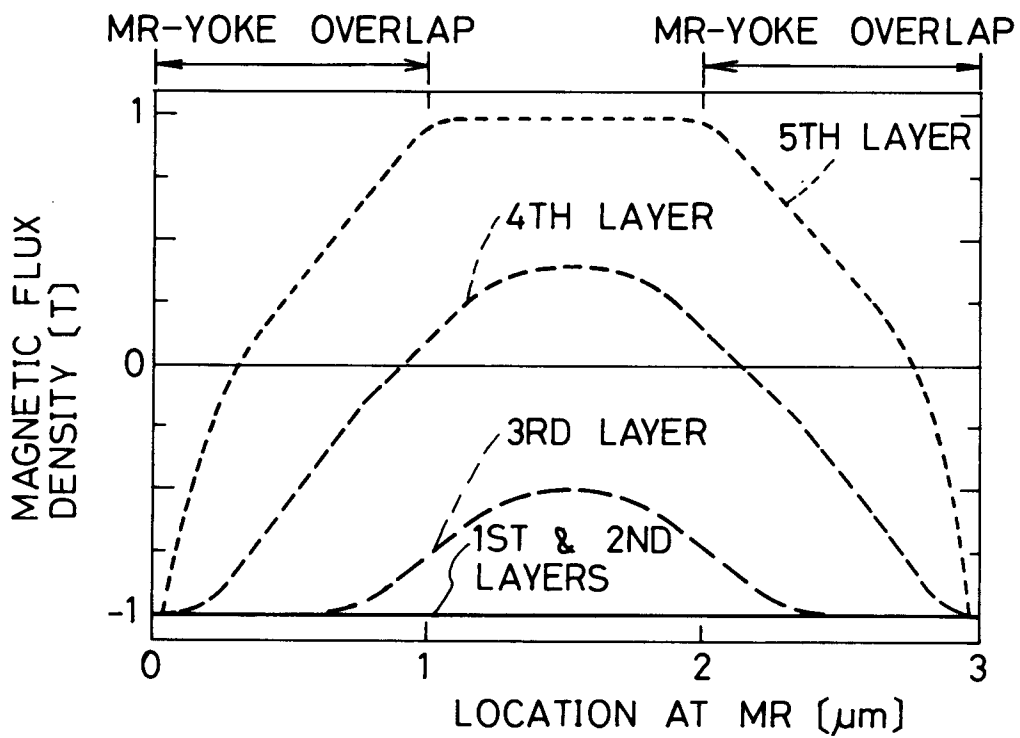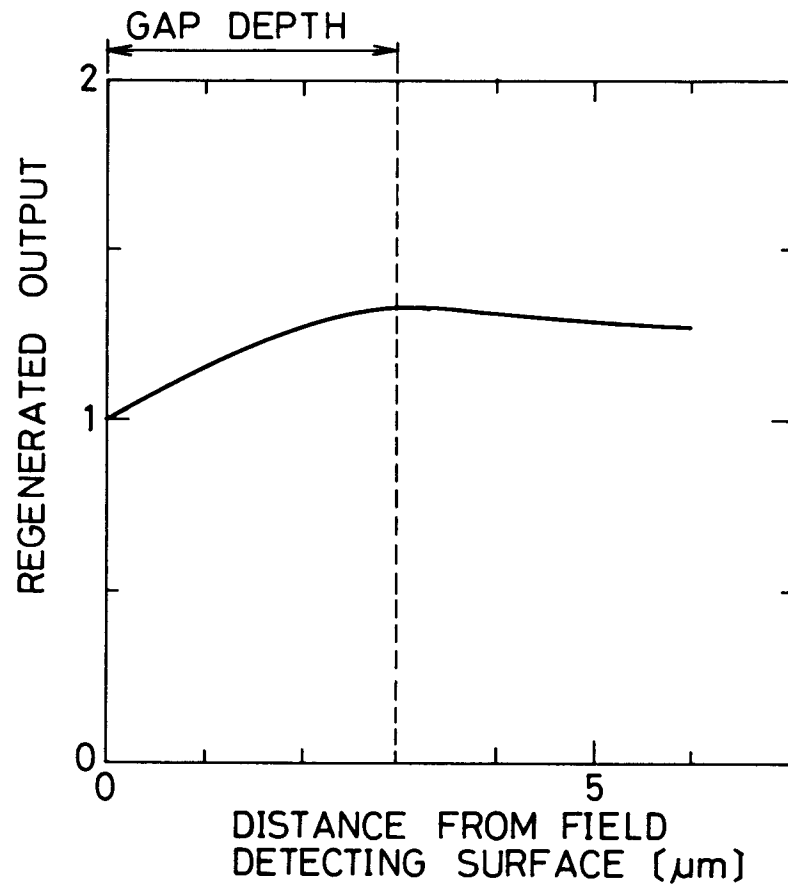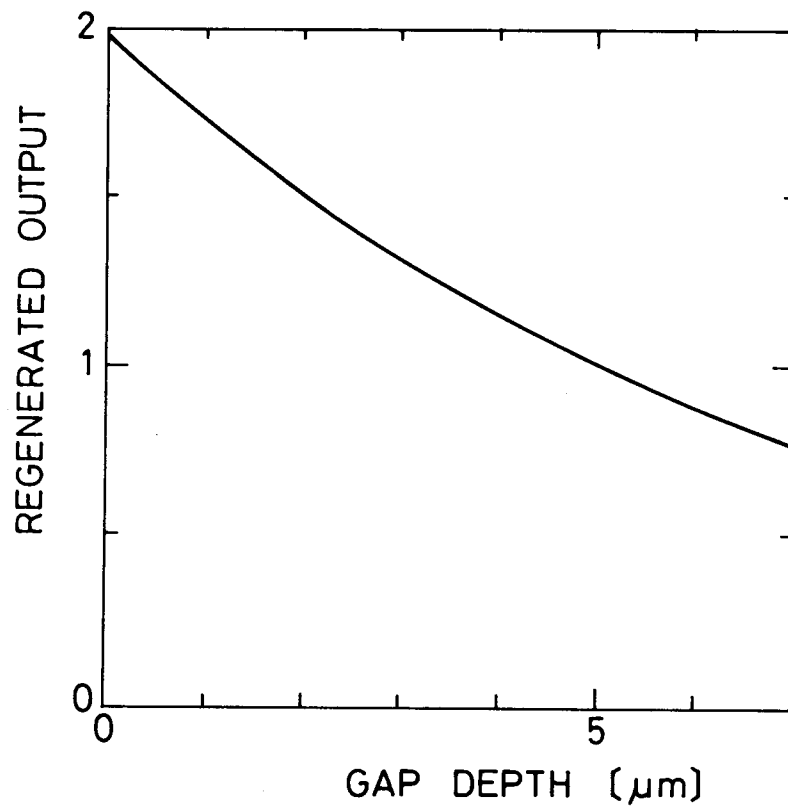
MR-YOKE OVERLAP   MR-YOKE OVERLAP

FIG.20

MR-YOKE OVERLAP   MR-YOKE OVERLAP

FIG. 21

GAP DEPTH

REGENERATED OUTPUT

DISTANCE FROM FIELD
DETECTING SURFACE (μm)

FIG. 22

REGENERATED OUTPUT

GAP DEPTH (μm)

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP-A-0 490 327 (HITACHI, LTD) 17 June 1992 * page 2, line 30 - line 52 * * page 3, line 42 - line 45 * ---	1-6,8-11	H01L43/08 G11B5/39
D,A	PHYSICAL REVIEW, B CONDENSED MATTER., vol. 43, no. 1, 1 January 1991 NEW YORK US, pages 1297-1300, DIENY B. ET AL. 'Giant magnetoresistance in soft ferromagnetic multilayers' * the whole document * ---	1,2,8,12	
A	PATENT ABSTRACTS OF JAPAN vol. 9 no. 207 (P-382) ,24 August 1985 & JP-A-60 069808 (SHARP KK) 20 April 1985, * abstract * -----	8-10	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 July 1995	De Laere, A